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What is the Final Verification of Engineering Requirements?

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“Systems Engineering” Session
Project Management Challenge 2010



Presentation Outline

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❖ Requirements Development

- Definition
- Documentation
- Maintenance

❖ Implementation

❖ Requirements Verification

- Methods
- Verification Plan
- Process

❖ Final Verification Approach



Requirements Definition

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- ❖ **Derived from higher level requirements (example shown next page)**
 - **Program requirements drive mission requirements**
 - **Mission requirements drive engineering solutions**
 - **Engineering solutions drive system requirements**
- ❖ **Requirements should be driven by basic needs**
 - **Wants or 'desirements' should be treated differently than requirements**
 - **Requirements should not specify engineering solutions**
- ❖ **Reviewed by both 'supplier' and 'customer'**
 - **Entity with the need is 'customer'**
 - **Entity that fulfills the need is 'supplier'**
 - **Both equally responsible for defining requirements**
 - **Iterative Process**
 - **Modifications may drive contractual changes**

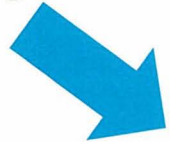


Requirements Derivation

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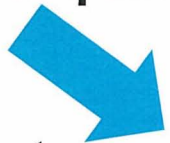
- **Program Goals**



- **Science Objectives**



- **Mission Requirements**



- **Instrument & System Requirements**



- **Subsystem & Component Requirements**



- **Drawings & Procedures**

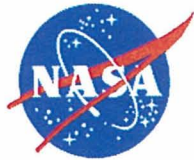


Requirements Documentation

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- ❖ **Requirements must have formal documentation, such as an Interface Control Document (ICD)**
 - **For higher level systems, can take years to develop**
 - **Approved by 'Supplier' and 'Customer'**
- ❖ **Only top level requirements are captured**
 - **Implementation and derived requirements are tracked internally by the supplier**
 - **Relevant, but not required, data should be kept out of the control document.**
- ❖ **The control documentation has contractual implications**
 - **Failure to meet the requirements is a breach of contract**
 - **Expansion of the requirements is a change in scope**



Requirements Maintenance

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- ❖ **Need to agree upon a formal requirement change/deviation/
variance/waiver process**
 - **Changes to track new direction or to fill in TBDs**
 - **Waivers, with rationale, to accept deviation from a
stated requirement**
 - **All parties who signed the original document must also
review and sign changes/waivers**

- ❖ **Contractual and technical issues must have separate
decision path**
 - **Implementation of new requirements may need
additional funding**
 - **If funding is not approved for a new requirement,
engineering team should have an avenue to elevate the
technical risk incurred**



We have requirements, now what?

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- ❖ **Engineering team leads development of the implementation solution**
 - **Starting from requirements, team designs the system**
 - **Draws from experience, history of successful systems**
 - **Seeks input from manufacturing and operations**

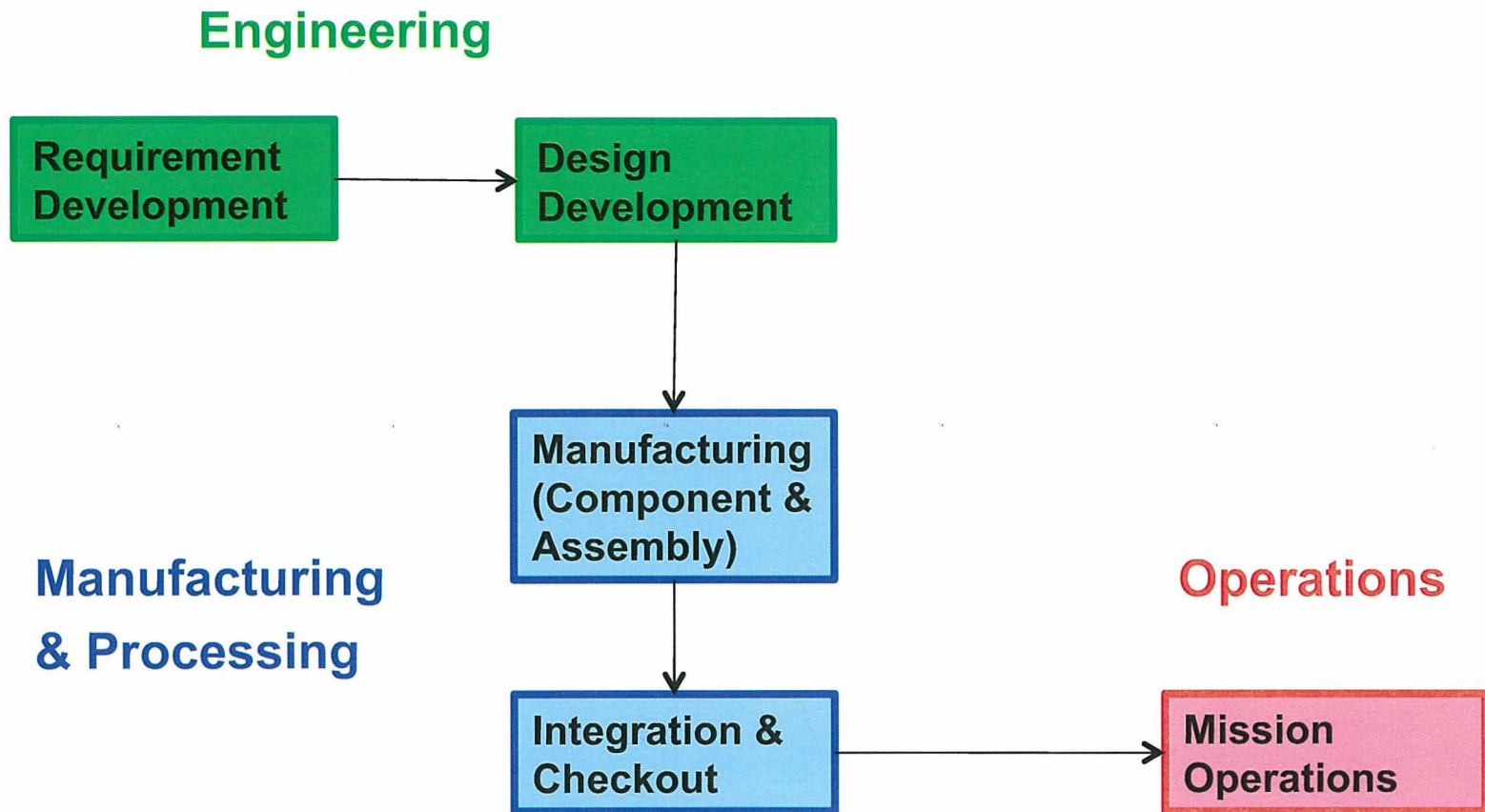
- ❖ **Final design is disseminated to other organizations**
 - **Drawings sent to manufacturing for production of operational units (flight hardware, GSE)**
 - **Procedures sent to operations for processing**



Requirements-to-Operations Flow

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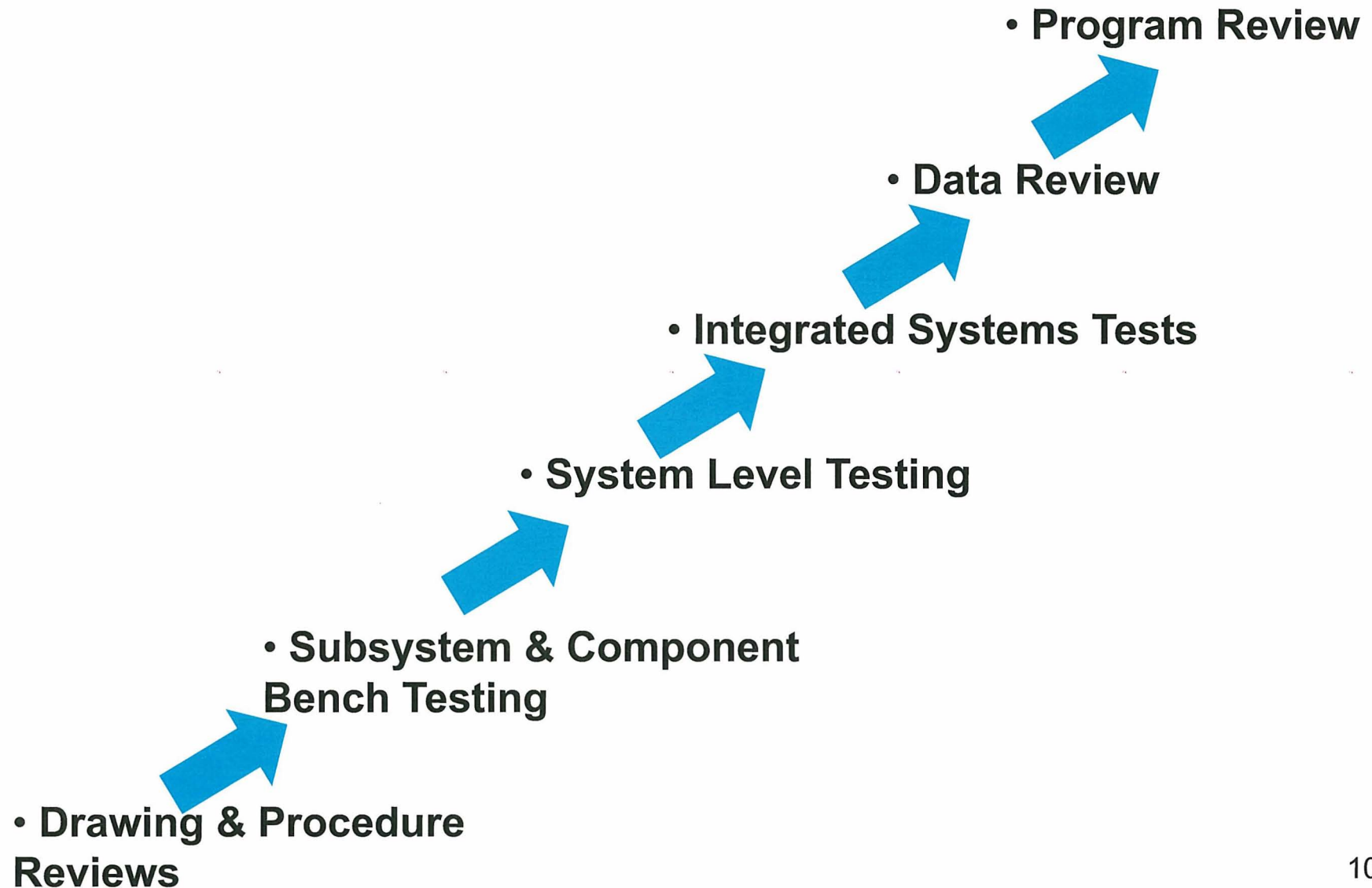
Verification

- ❖ **Final operational system must satisfy original requirements**
 - **Systematic verification offers good protection against failure**
 - **Verification of system performance reduces unexpected system behavior**
 - **A formal process is required to document the methods used**

- ❖ **Many verifications can be performed along the way to reduce schedule risk**
 - **Waiting until the system is operational to verify requirements is too late**
 - **Performing incremental verification reduces risk of performing the next step in the process**



Verification Strategy





Verification Methods

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❖ Test

- Qualification testing – verification of the design through testing to extremes of use environment
- Acceptance testing – verification that a unit has been built per the design
- Lot Acceptance Test – testing of a sampling of units to verify the entire lot is acceptable (ordnance)

❖ Inspection

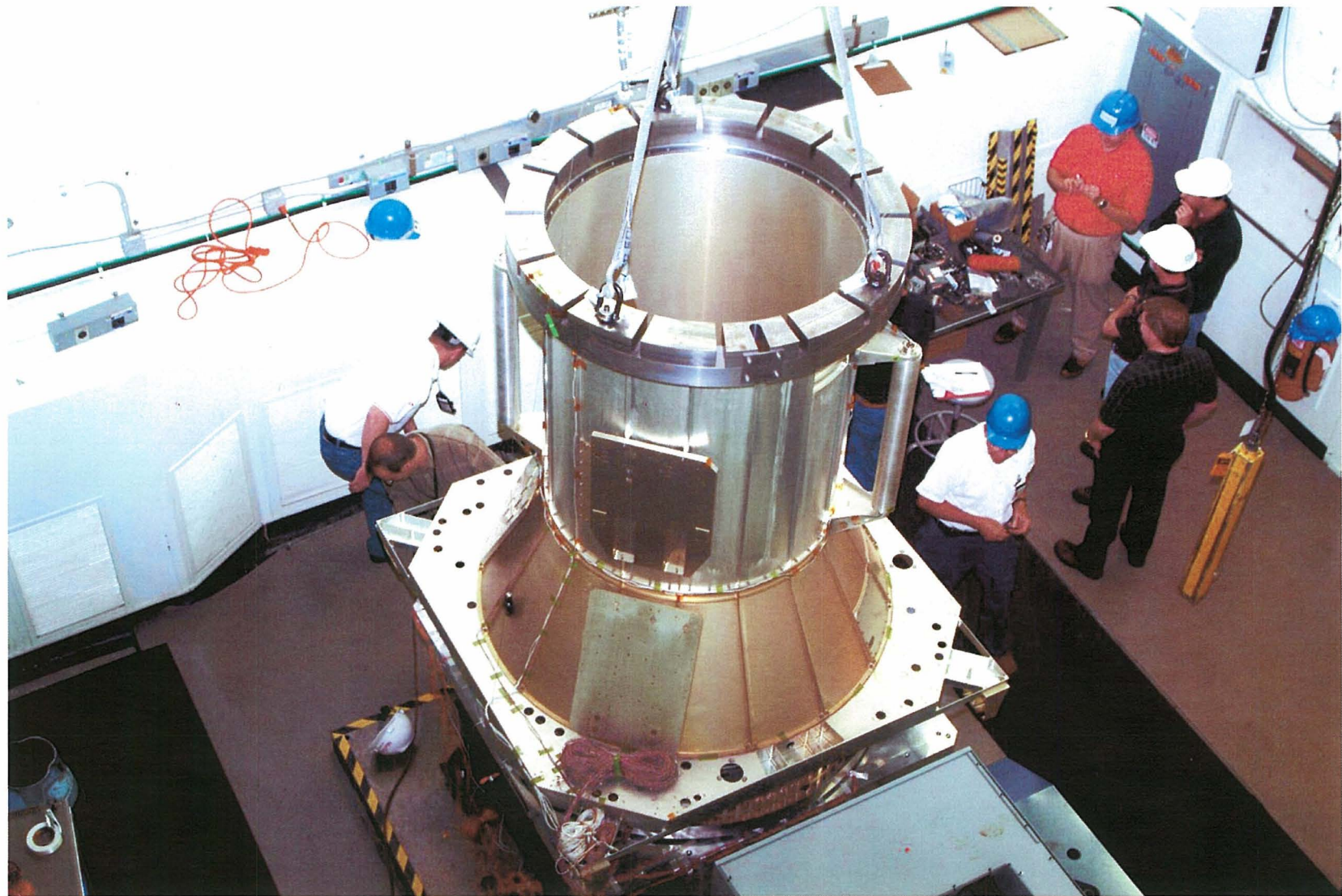
- Review of documentation (drawings, procedures) to verify that requirements have been properly disseminated, or “flowed down”
- Review of hardware to verify implementation is correct
 - ❖ Connectors
 - ❖ Tubing
 - ❖ Etc.



Spacecraft Bus Vibration Testing

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Verification Methods (continued)

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❖ Analysis

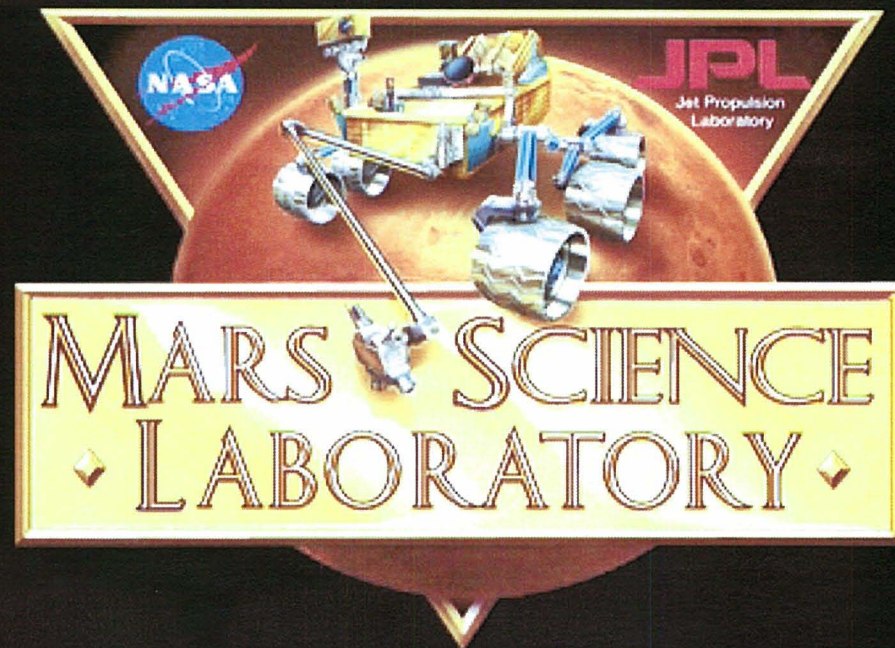
- Calculation of predicted performance based on worst case scenario
- Not a preferred method, but necessary in some cases (e.g. rocket flight trajectory)

❖ Demonstration

- Operation of an item to show that the item is capable of fulfilling its intended purpose
- Can be used to verify hardware, software or procedures



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FULL MOTION SEPARATION TEST SERIES

PLA SEPARATION
25 AUGUST/2008

CAPTURE: 2,000 FPS
REPLAY: 30 FPS
APX CAMERA

RAM



Verification Plan

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- ❖ **Once the requirements are documented, a plan for the specifics of verification is needed**
 - **Every requirement must be formally verified**
 - **Methods specified**
 - **Responsible organization specified.**
 - **Multiple verifications for one requirement is common**
 - **Incremental verifications can be documented, but one final verification is sufficient.**

- ❖ **Verification plan is reviewed by all parties**
 - **One party responsible for maintaining the plan**
 - **Changes must be reviewed by all and documented**



Verification Process

- ❖ **The responsible party performs the verification**
- ❖ **A summary of the verification performed, along with supporting documentation, is distributed to all parties**
- ❖ **Reviewers clarify any questions**
- ❖ **Final verification documented and closed by each party**



Midpoint Review

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- ❖ **In the beginning, there is an engineering team that develops a design solution**
 - **Team primarily composed of specialized, highly trained (expensive) personnel**
 - **The end product of this team is a paper (electronic?) design**
 - **The design gets passed on to other teams who are expert at the tasks of manufacturing and processing**
 - **The completed system gets passed on to another team, tasked with operating the system**

- ❖ **In the end, we want a system that meets the mission objectives, and was completed on time and within the given budget**



Cradle-to-Grave Engineering

VS.

Passing the Baton



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Continuous Involvement

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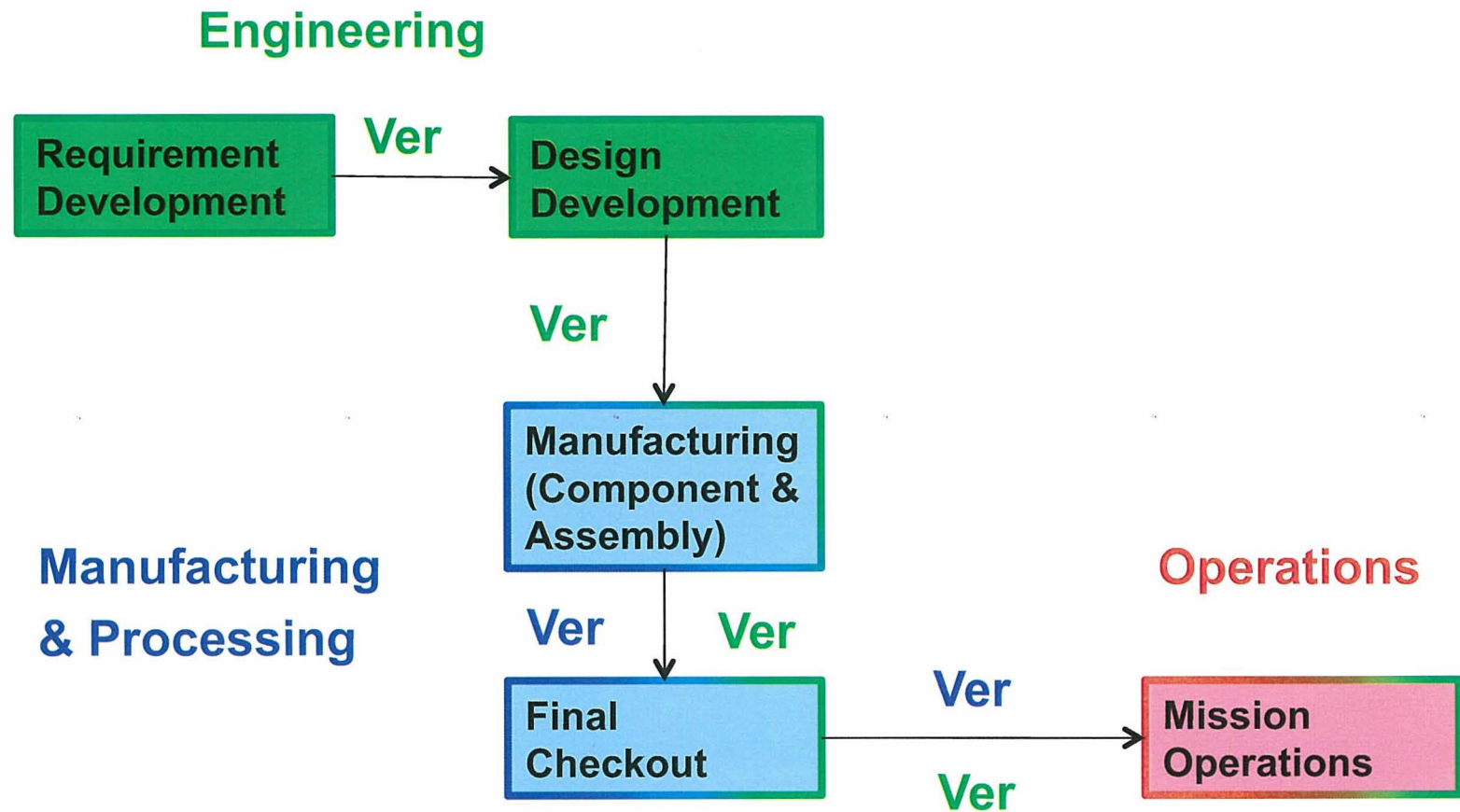
- ❖ **Engineering team determines requirements, develops design solution**
- ❖ **When manufacturing begins, engineering team continues to follow the process**
 - **Ensures parts are built as intended**
 - **Allows engineers to spot unforeseen flaws in the design**
- ❖ **During final processing flow, engineering team follows the operations**
 - **Ensures system operates as intended**
 - **Aides trouble shooting if problems arise during check-out**
- ❖ **During mission operations, engineering team on hand to help trouble-shooting**



Continuous Involvement Flow

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Continuous Involvement Responsibility Table

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Event	Verification	Responsibility
Requirement Documentation	Documentation Review	Engineering
Implementation Design	Drawing, Procedure Review	Engineering
Component Manufacture	Receiving Inspection	M&P, Engineering
Systems Integration	As-run procedure	M&P, Engineering
System Test	Test results	M&P, Engineering



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Mission Relay

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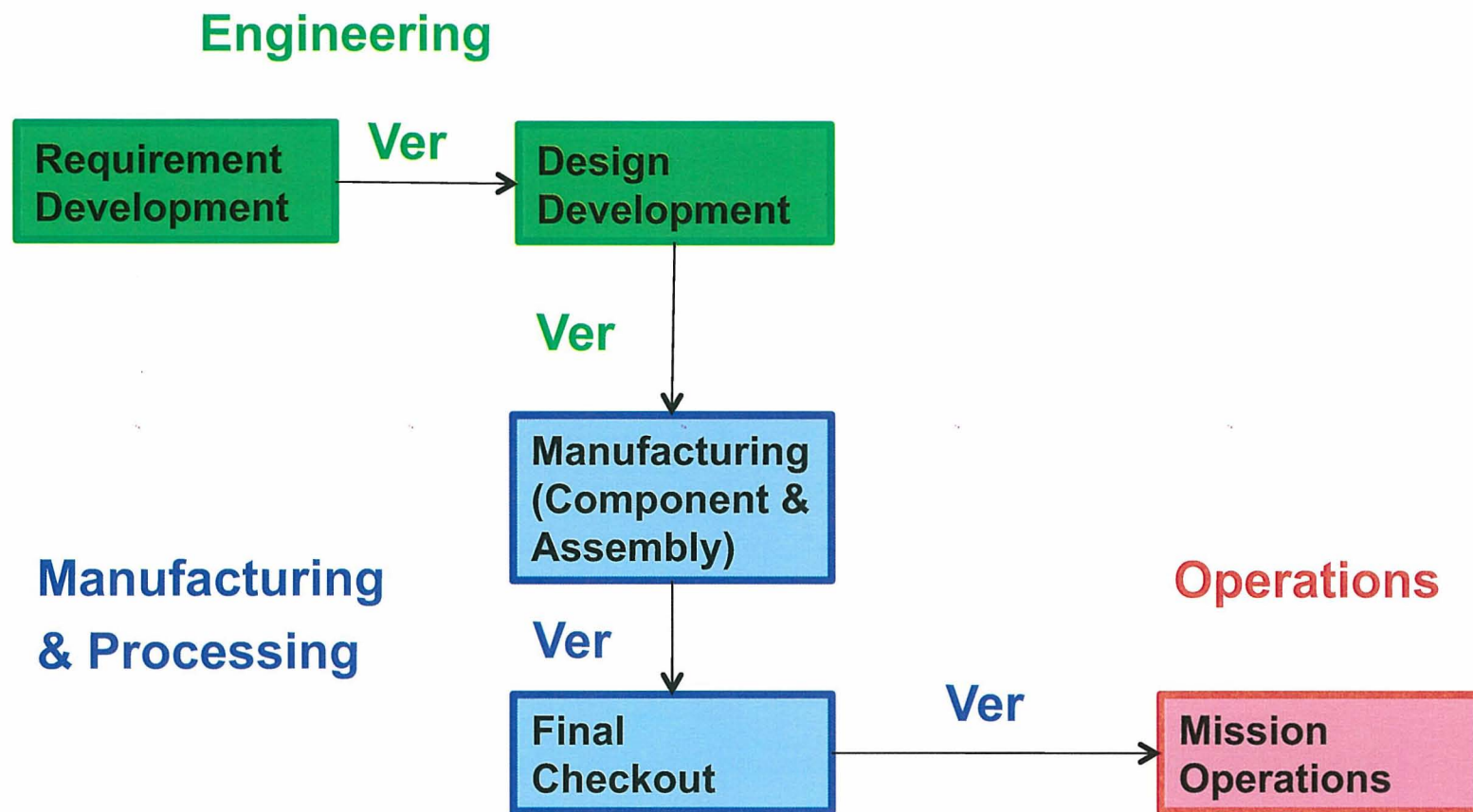
- ❖ **Engineering team determines requirements, develops design solution**
- ❖ **When manufacturing begins, engineering team hands off to the manufacturing center**
 - **Parts built per drawing**
 - **If questions arise, engineering team can be consulted**
- ❖ **During final processing flow, manufacturing center hands off to operations team**
 - **Assembly and check out done per procedure**
 - **If questions arise, engineering team can be consulted**
- ❖ **During mission operations, any of the above groups can be consulted for trouble shooting**



Mission Relay Flow

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Mission Relay Responsibility Table

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Implementation Design	Drawing, Procedure Review	Engineering
Component Manufacture	Receiving Inspection	M&P
Systems Integration	As-run procedure	M&P
System Test	Test results	M&P



Final Verification

- ❖ **Final verification of the mission system occurs as an integrated system test, just before deploying the system in to the operations phase**
 - **There is little disagreement that an integrated, system-level test should be performed**
 - **Exercising the system significantly reduces implementation risk and often finds errors**
- ❖ **Debate is really over who performs the verification – Should the original development team continue to follow process all the way through to operations?**



Closing

- ❖ **Mission Success is the main objective**
 - **NASA missions are typically one-of-a-kind, never-been-done-before operations**
 - **There is plenty of room for error and misunderstanding when passing off designs**
 - **Personnel continuity through the phases increases the probability of mission success**

- ❖ **High cost is a major obstacle to receiving approval for missions**
 - **Mission costs are strongly influenced by labor hours**
 - **Many aspects of space operations have been done before**
 - **Experienced manufacturing and operations personnel can mitigate risk of misunderstanding**



As Always, the Answer is . . .

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